

Summary of Science Driven Telescope Specifications

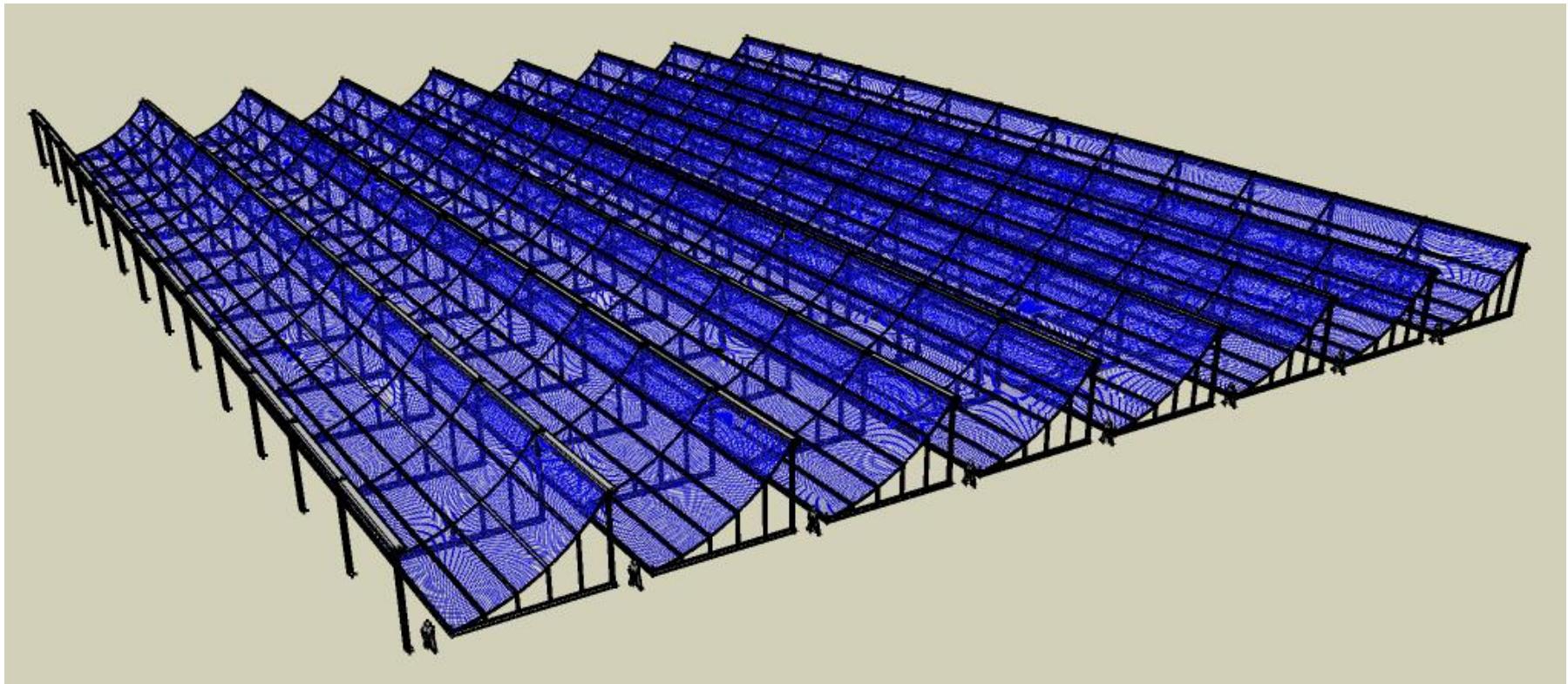
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Requirement Process

- Define the science
 - Dark energy
- Define parameter that measures success
 - Dark Energy Task force Figure of Merit
- Define science technique
 - Baryon Acoustic Oscillations with intensity mapping
- Pick an Instrument
 - Develop a rough engineering model
 - Estimate the cost versus science of the instrument
 - Pick a parameter set or “punt”

Instrument

The Cylindrical Radio Telescope Array (CRT)



The CRT

- An array of cylindrical telescopes in which each cylinder is oriented along the north-south meridian
- The telescope operates in a drift scan mode. The cylinders are fixed.
- Along the focus of each cylinder is a uniformly spaced array of antenna feeds
- The antenna beams along the north-south meridian are formed by taking the spatial Fourier transform of the array of antenna feeds
- The antenna beams along the east-west direction are formed by either correlations or a Fourier transform.

The CRT

- Advantages
 - Survey area (lots of pixels)
 - Signal to Noise (lots of redundant baselines)
 - Simplicity (no moving parts)
- Disadvantages
 - Calibration
 - Lose phase information? (zero-padding?)
 - Individual feeds see all of the sky - no strong point sources
 - Pair correlation calibration is a concept that can work but requires extra hardware
 - Resolution
 - No source tracking

CRT Constraints

- Divide survey into two by dividing frequency span into two bands
 - Performance maximized by noise performance
 - Noise match easier over smaller bandwidth
 - Larger digitizer dynamic range for smaller bandwidth
- Bands are adjacent
- Fractional bandwidth of each band $< 33\%$
- Limit the maximum span to half the digitizer bandwidth
- Digital electronics are re-used for each band
- Number of electronic channels are the same for both bands
- Reflector width and spacing the same for both bands

Parameter Set

- Static Engineering Parameters (STE)
- Dynamic Engineering Parameters (DYE)
- Derived Engineering Parameters (DRE)
- Scientific Parameters (SCI)

Parameter Set

- Static Engineering Parameters (STE)
 - The static engineering parameters are independent parameters that are
 - important in describing the telescope
 - not easily changed for design optimization
 - such as the latitude of the telescope site, amplifier temperature, etc.

Static Engineering Parameters (STE)

Number	Description	Symbol
STE.01	Survey Time	τ_s
STE.02	Observing Duty Factor	D_f
STE.03	Latitude of telescope site	α_L
STE.04	Average Sky Temperature	T_s
STE.05	Maximum Frequency Span per band	$\Delta F_{b\max}$
STE.06	Maximum Fractional Bandwidth per band	δ_{f_b}
STE.07	Number of Polarizations	N_p
STE.08	Antenna Feed Power Efficiency	g_a
STE.09	Cylinder Width / Cylinder Spacing	x_{cyl}
STE.10	Equivalent Amplifier Temperature	T_A
STE.11	Electronics Cost per Channel	R_e
STE.12	Feed Structure Cost per meter	R_f
STE.13	Reflector Cost per Cylinder volume	R_r

Dynamic Engineering Parameters (DYE)

- Dynamic engineering parameters are independent parameters that can be easily varied during the design stage
 - such as feed spacing and the number of channels per cylinder

Number	Description	Symbol
DYE.01	Center Frequency of both bands combined	F_c
DYE.02	Average Feed Spacing	D_f
DYE.03	Number of digital channels per cylinder per polarization	N_f
DYE.04	Average Number of possible cylinder locations	N_L
DYE.05	Average Cylinder packing factor	p_f
DYE.06	Target Cost	C_T

Derived Engineering Parameters (DRE)

- Derived engineering parameters are design specific parameters
 - such as cylinder length and width
 - but are derived from the static and dynamic engineering parameters.

Derived Engineering Parameters (DRE)

Number	Description	Symbol
DRE.01	Number of Cylinders	N_c
DRE.02	Cylinder Length	L_c
DRE.03	Cylinder Width	W_c
DRE.04	Cylinder Spacing	S_c
DRE.05	Declination Span	$\Delta\theta_d$
DRE.06	Feed Length	h_f
DRE.07	Feed Spacing	d_f
DRE.08	Band Center Frequency	F_{cb}
DRE.09	Wavelength	λ
DRE.10	Band Frequency Span	ΔF_b
DRE.11	Resolution Bandwidth	δf
DRE.12	Minimum Digital Memory	M_d
DRE.14	Integration Time per Pixel	τ_p
DRE.15	Number of Channels per polarization	N_{fT}
DRE.16	Electronics Cost	C_e
DRE.17	Feed Structure Cost	C_f
DRE.18	Reflector Cost	C_R
DRE.19	Total Cost	C_T

Derived Engineering Parameters (DRE)

$$\delta_f < \frac{F_c}{\Delta F_{bmax}} - \frac{2}{1 + \sqrt{\frac{4F_c - \Delta F_{bmax}}{2F_c}}}$$

$$F_{c\pm} = F_c \frac{4 \pm 2\delta_f}{4 + \delta_f^2}$$

$$\Delta F_{\pm} = \delta_f F_{c\pm}$$

$$N_{L\pm} = round\left(N_L \frac{F_c}{F_{c\pm}}\right)$$

$$d_{f\pm} = D_f N_{L\pm}$$

$$p_{f+} = p_{f-} \frac{N_{L-}}{N_{L+}}$$

$$N_{f+} = N_{f-} = N_f$$

$$N_{C+} = N_{C-} = N_C = p_{f-} N_{L-}$$

$$R_{\pm} = \frac{1}{2} \frac{N_C (N_C - 1)}{N_{L\pm} - 1}$$

$$N_C > \frac{1}{2} \left(1 + \sqrt{1 + 8(N_{L-} - 1)} \right)$$

$$p_{f-} > \frac{1}{2N_{L-}} \left(1 + \sqrt{1 + 8(N_{L-} - 1)} \right)$$

$$L_{C\pm} = N_f d_{f\pm}$$

$$W_C = x_{cyl} S_C = x_{cyl} \frac{N_f d_{f\pm}}{N_{L\pm}}$$

$$\sin\left(\frac{\Delta\theta_{d\pm}}{2}\right) = \frac{\lambda}{2d_{f\pm}}$$

$$A_f = h_f W_C$$

$$\sin\left(\frac{\Delta\theta_f}{2}\right) = \frac{\lambda}{2h_f}$$

$$h_{f\pm} = d_{f\pm}$$

Telescope Cost

- It is not intended that these costs include everything that would arise in designing and building a large radio telescope
 - such as site preparation, non-recoverable engineering costs, overhead, contingency etc.,
- These costs should only be used in trying to compare sets of design parameters.
- The cost of the digital electronics is assumed to scale only with the number of feeds:

$$C_e = N_f N_c N_p R_e$$

Telescope Cost

- The cost of the telescope structure is broken into two parts.
- The feed line is the most complicated part of the reflector system and this cost will scale as the total length of the array.

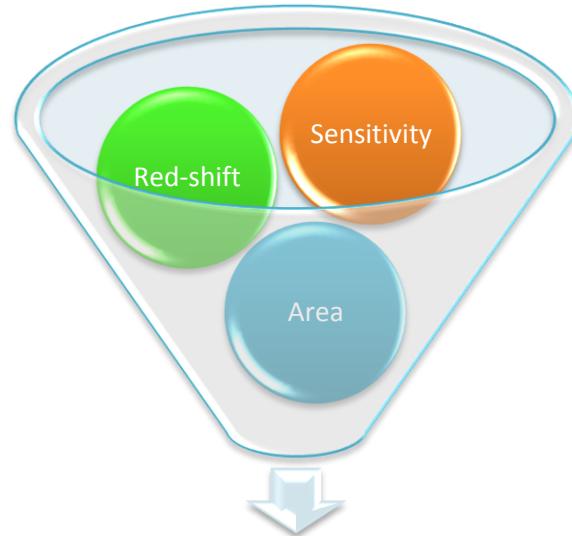
$$C_f = L_c N_c R_f = N_f N_c d_f R_f$$

- The cost of the main reflector surface will not only be proportional to area
 - but height as well since tall structures will be more difficult to build.
 - For a fixed f-ratio, the height will scale with cylinder width.

$$C_r = L_c N_c W_c^2 R_f = N_f N_c d_f W_c^2 R_f$$

Scientific Parameters (SCI) (a.k.a. the 5 magic numbers)

- We want to have a set of numbers that
 - Describe the science
 - Can be derived from **ANY** telescope configuration
- The magic numbers for determining dark energy parameters using BAO
 - Minimum red-shift
 - Maximum red-shift
 - Survey area
 - Pixel Resolution
 - Pixel Sensitivity



Scientific Parameters (SCI)

Number	Description	Symbol
SCI.01	Maximum Red-shift	z_{max}
SCI.02	Minimum Red-shift	z_{min}
SCI.03	Angular Resolution	$\delta\psi$
SCI.04	Survey Area	A_s
SCI.05	Sensitivity per Pixel	δT_p
SCI.06	Figure of Merit with Plank Priors	FoM_p
SCI.07	Figure of Merit with Stage II Dark Energy Priors	FoM_{II}

Scientific Parameters (SCI)

$$z_{min\pm} = \frac{1.42GHz}{F_{c\pm} - \frac{1}{2}\Delta F_{\pm}} - 1$$

$$M_{d\pm} = \frac{2\Delta F_{\pm}}{\delta f_{\pm}}$$

$$z_{\pm} = \frac{1.42GHz}{F_{c\pm}} - 1$$

$$A = \int_0^{2\pi} d\phi \int_{\theta_{d\min}}^{\theta_{d\max}} \cos(\theta) d\theta = 2\pi [\sin(\theta_{d\max}) - \sin(\theta_{d\min})]$$

$$z_{max\pm} = \frac{1.42GHz}{F_{c\pm} + \frac{1}{2}\Delta F_{\pm}} - 1$$

$$\sin(\delta\psi_{\pm}) = \frac{\lambda}{N_f d_{f\pm}}$$

$$\delta z_{\pm} \approx 0.436 \times \delta\psi_{\pm} (\text{radians}) \times z_{\pm} (z_{\pm} + 2)$$

$$\delta f_{\pm} = \frac{1.4GHz}{(1+z_{\pm})^2} \delta z_{\pm}$$

$$\theta_{d\max} = \alpha_L + \frac{\Delta\theta_d}{2} \quad \text{if} \quad \alpha_L + \frac{\Delta\theta_d}{2} < \frac{\pi}{2}$$

$$\theta_{d\max} = \frac{\pi}{2} \quad \text{if} \quad \alpha_L + \frac{\Delta\theta_d}{2} > \frac{\pi}{2}$$

$$\theta_{d\min} = \alpha_L - \frac{\Delta\theta_d}{2} \quad \text{if} \quad \alpha_L - \frac{\Delta\theta_d}{2} < -\frac{\pi}{2}$$

$$\theta_{d\min} = -\frac{\pi}{2} \quad \text{if} \quad \alpha_L - \frac{\Delta\theta_d}{2} < -\frac{\pi}{2}$$

Scientific Parameters (SCI)

$$\sin(\psi_n) = \left(-\frac{1}{2} + \frac{n}{N_f} \right) \frac{\lambda}{d_f}$$

$$\theta_n = \psi_n + \alpha_L$$

$$\Delta\phi_C = \frac{\lambda}{W_c}$$

$$\sin\left(\frac{\Delta\varphi_{RA_n}}{2}\right) = \frac{1}{\cos(\theta_n)} \sin\left(\frac{\Delta\phi_C}{2}\right)$$

$$\tau_p = \frac{\tau_s D_f}{N_f + 1} \sum_{n=0}^{N_f} \frac{\Delta\varphi_{RA_n}}{2\pi}$$

$$\delta T_{p\pm} = \frac{1}{\sqrt{\tau_{p\pm} \delta f_\pm}} \left(T_s + \frac{1}{g_a} \frac{1}{p_{f\pm}} \frac{d_{f\pm}}{h_{f\pm}} \sqrt{\frac{N_f}{(N_f - 1)}} \sqrt{\frac{N_c}{(N_c - 1)}} T_A \right)$$

Requirement Optimization

- Developed a web application to evaluate parameter sets
 - Helps with focus loosely organized world-wide collaboration
- Uses Hee-Jong's BAO analysis technique for determining Figure of Merit
- Web application has two features
 - Evaluator
 - Optimizer

Requirement Optimizer

- Vary
 - Center Frequency
 - Feed spacing
 - Number of cylinder locations
 - Cylinder packing factor
- Constrain
 - Number of feeds per cylinder to reach target cost

Requirement Web Application

CRT Design Requirements II

http://crt21cm3.final.gov:8080/CrtMagicNumbers/magicNumberII.jsp

Calculate FoM Optimize Iterations 40

	Band 1			Target	Step	Band 2			
SCI.01 - Redshift Range	1.8	1.33	1			1	0.67	0.43	pi Steradians
SCI.02	3.64	2.81	2.41			3.64	3.05	2.58	
SCI.03 Survey Area	17.11	14.26	12.22			18.33	15.28	13.09	arc-min
SCI.04 Angular Resolution	87.37	104.74	194.42			74.76	91.53	172.33	uK
SCI.05 Sensitivity per Pixel		89.67		89.67			89.67		
SCI.06 Plank Priors Figure of Merit		235.84		235.84			235.84		
SCI.07 DE II Priors Figure of Merit									
DYE.01 Center Frequency	600		740	0		840			MHz
DYE.02 Feed Spacing	0.5838		0.6	0		0.5449			lambda
DYE.03 Digital Channels per Cylinder per Polarization	413		413			413			
DYE.04 Number of Cylinder locations	6		5	2		4			
DYE.05 Cylinder Packing Factor	66.67		60	20		100			%
DYE.06 Total Cost	15.01		15.0			13.31			M\$
STE.01 Survey Time	2		2.0			2			years
STE.02 Observing Duty Factor	50		50.0			50			%
STE.03 Latitude	35		35.0			35			degrees

Microsoft PowerPoint - [FermilabScienceReq.pptx]

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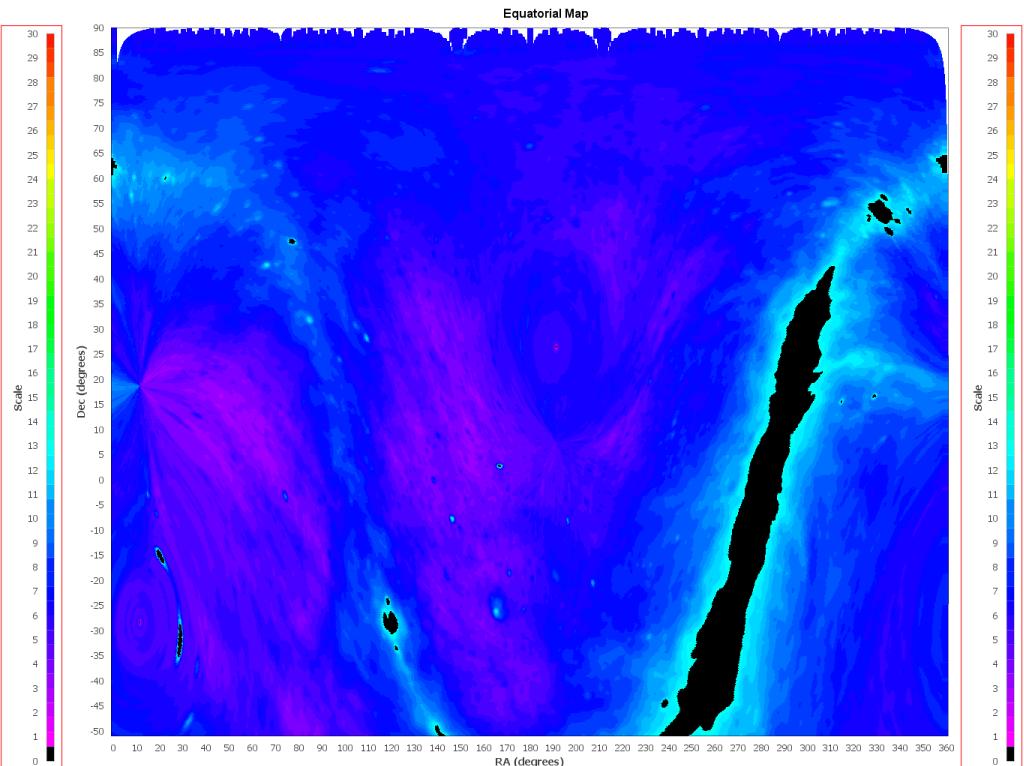
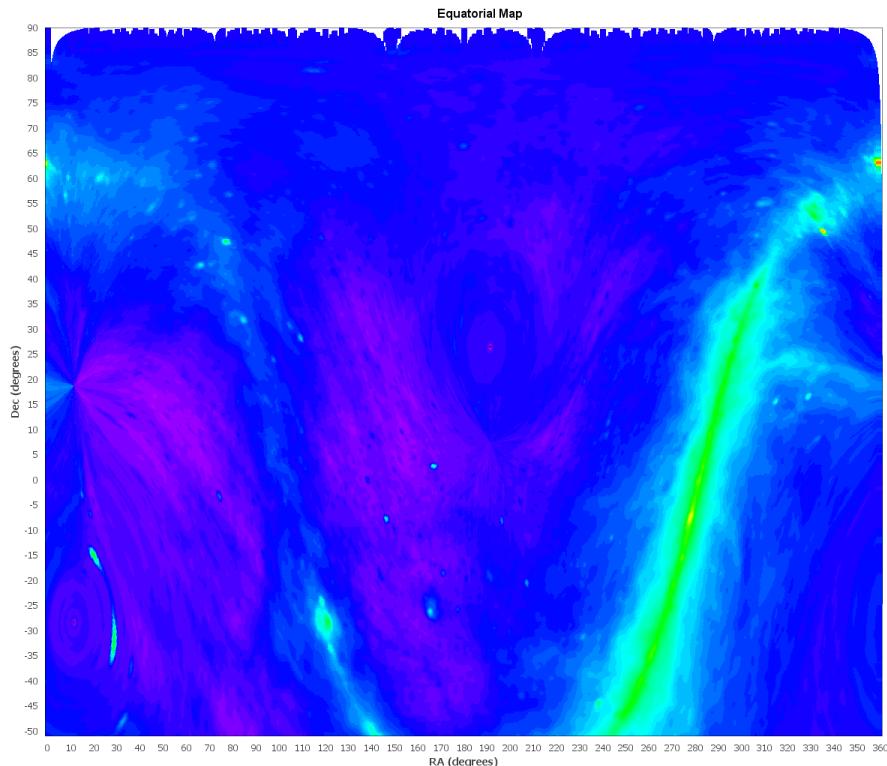
Requirement Web Application

CRT Design Requirements II				
http://crt21cm3.fnal.gov:8080/CrtMagicNumbers/magicNumberII.jsp				
iGoogle Google Calendar Gmail Google Docs localMagicNo remoteMagicNo Wavelet Filter MagicSpyFile WaveSpy Science w/ Fast Radio...				
STE.08	Antenna Efficiency	80	80.0	80 %
STE.09	Antenna Width Fill Factor	80	80.0	80 %
STE.10	Amplifier Temperature	50	50.0	50 K
STE.11	Electronics Cost per Channel	3000	3000.0	3000 \$
STE.12	Feed Structure Cost Rate	2300	2300.0	2300 \$/meter
STE.13	Reflector Volume Cost Rate	32	32.0	32 \$/meter^3
DRE.01	Number of Cylinders	4		4 meters
DRE.02	Cylinder Length	120.55		80.37 meters
DRE.03	Cylinder Width	16.07		16.07 meters
DRE.04	Cylinder Spacing	20.09		20.09 meters
DRE.05	Declination Span	180	117.85	180 133.17 103.73 degrees
DRE.06	Feed Length		94.47	19.46 cm
DRE.07	Feed Spacing			19.46 cm
DRE.08	Frequency	500	600	700 840 980 MHz
DRE.09	Wavelength	60	50	42.86 35.71 30.61 cm
DRE.10	Frequency Span			280 MHz
DRE.11	Res. Bandwidth	2.65	2.07	2.44 1.73 1.18 MHz
DRE.12	Minimum Digital Memory			472
DRE.13	Integration Time per Pixel	8.02	7.16	5.74 5.39 2.23 days
DRE.14	Number of Channels per polarization			1652
DRE.15	Electronics Cost			9.91 M\$
DRE.16	Feed Structure Cost			0.74 M\$
DRE.17	Reflector Volume Cost			2.66 M\$

Static Engineering Parameters

	Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
STE.01	Survey Time	2	2	2	2	2	2	2	2	2	2	2	2	2	2 years
STE.02	Observing Duty Factor	50	50	50	50	50	50	50	50	50	50	50	50	50	50 %
STE.03	Latitude	35	35	35	35	35	35	35	35	35	35	35	35	35	35 degrees
STE.04	Avg. Sky Temperature	10	10	10	10	10	10	10	10	10	10	10	10	10	10 K
STE.05	Maximum Span	300	300	300	300	300	300	300	300	300	300	300	300	300	300 MHz
STE.06	Center Freq / Freq Span	3	3	3	3	3	3	3	3	3	3	3	3	3	3
STE.07	Number of Polarizations	2	2	2	2	2	2	2	2	2	2	2	2	2	2
STE.08	Antenna Efficiency	80	80	80	80	80	80	80	80	80	80	80	80	80	80 %
STE.09	Antenna Width Fill Factor	80	80	80	80	80	80	80	80	80	80	80	80	80	80 %
STE.10	Amplifier Temperature	50	50	50	50	50	50	50	50	50	50	50	50	50	50 K
STE.11	Electronics Cost per Channel	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000 \$
STE.12	Feed Structure Cost Rate	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300 \$/meter
STE.13	Reflector Volume Cost Rate	32	32	32	32	32	32	32	32	32	32	32	32	32	32 \$/meter^3

Sky Temperature



No Cut – 100% used

Average Temperature = 6.5K at
750 MHz

Latitude = 35 degrees

Cut at 20K-96% used

Average Temperature = 5.3K at
750 MHz

Dynamic Engineering Parameters

	Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
DYE.01	Center Frequency	600	600	600	600	600	600	600	600	600	600	600	600	600	MHz
DYE.02	Feed Spacing	0.5838	0.5676	0.5838	0.5838	0.5676	0.5838	0.5676	0.5676	0.5676	0.5676	0.5838	0.5676	0.5838	lambda
DYE.03	Digital Channels per Cylinder per Polarization	175	326	413	493	474	493	534	533	563	587	610	749	718	
DYE.04	Number of Cylinder locations	6	7	6	6	7	6	7	7	7	7	6	7	6	
DYE.05	Cylinder Packing Factor	66.67	57.14	66.67	66.67	85.71	100	114.29	142.86	157.14	171.43	183.33	142.86	166.67	%
DYE.06	Total Cost	4.97	10	15.01	19.94	25.02	29.91	40.06	49.92	59.95	70.05	80.09	89.97	100.27	M\$

Band 1

	Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
DYE.01	Center Frequency	840	840	840	840	840	840	840	840	840	840	840	840	840	MHz
DYE.02	Feed Spacing	0.5449	0.5676	0.5449	0.5449	0.5676	0.5449	0.5676	0.5676	0.5676	0.5676	0.5449	0.5676	0.5449	lambda
DYE.03	Digital Channels per Cylinder per Polarization	175	326	413	493	474	493	534	533	563	587	610	749	718	
DYE.04	Number of Cylinder locations	4	5	4	4	5	4	5	5	5	5	4	5	4	
DYE.05	Cylinder Packing Factor	100	80	100	100	120	150	160	200	220	240	275	200	250	%
DYE.06	Total Cost	4.72	9.38	13.31	17.24	22.75	25.85	35.94	44.8	53.44	62.11	66.81	77.1	81.21	M\$

Band 2

Derived Engineering Parameters

	Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
DRE.01	Number of Cylinders Band 1	4	4	4	4	6	6	8	10	11	12	11	10	10	
DRE.02		51.08	92.51	120.55	143.9	134.51	143.9	151.54	151.26	159.77	166.58	178.05	212.55	209.58	meters
DRE.03		6.81	10.57	16.07	19.19	15.37	19.19	17.32	17.29	18.26	19.04	23.74	24.29	27.94	meters
DRE.04		8.51	13.22	20.09	23.98	19.22	23.98	21.65	21.61	22.82	23.8	29.68	30.36	34.93	meters
DRE.05		117.85	123.51	117.85	117.85	123.51	117.85	123.51	123.51	123.51	123.51	117.85	123.51	117.85	degrees
DRE.06		29.19	28.38	29.19	29.19	28.38	29.19	28.38	28.38	28.38	28.38	29.19	28.38	29.19	cm
DRE.07		29.19	28.38	29.19	29.19	28.38	29.19	28.38	28.38	28.38	28.38	29.19	28.38	29.19	cm
DRE.08		600	600	600	600	600	600	600	600	600	600	600	600	600	MHz
DRE.09		50	50	50	50	50	50	50	50	50	50	50	50	50	50 cm
DRE.10		200	200	200	200	200	200	200	200	200	200	200	200	200	MHz
DRE.11		4.87	2.69	2.07	1.73	1.85	1.73	1.64	1.65	1.56	1.49	1.4	1.17	1.19	MHz
DRE.12		104	188	245	293	274	293	309	308	325	339	363	433	427	
DRE.13		14.53	10.29	7.16	6.12	7.48	6.12	6.75	6.76	6.45	6.26	5.1	5.08	4.44	days
DRE.14		700	1304	1652	1972	2844	2958	4272	5330	6193	7044	6710	7490	7180	
DRE.15		4.2	7.82	9.91	11.83	17.06	17.75	25.63	31.98	37.16	42.26	40.26	44.94	43.08	M\$
DRE.16		0.47	0.85	1.11	1.32	1.86	1.99	2.79	3.48	4.04	4.6	4.5	4.89	4.82	M\$
DRE.17		0.3	1.32	3.99	6.78	6.1	10.17	11.64	14.46	18.75	23.18	35.32	40.14	52.37	M\$

	Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
DRE.01	Number of Cylinders Band 2	4	4	4	4	6	6	8	10	11	12	11	10	10	
DRE.02		34.05	66.08	80.37	95.94	96.08	95.94	108.24	108.04	114.12	118.99	118.7	151.82	139.72	meters
DRE.03		6.81	10.57	16.07	19.19	15.37	19.19	17.32	17.29	18.26	19.04	23.74	24.29	27.94	meters
DRE.04		8.51	13.22	20.09	23.98	19.22	23.98	21.65	21.61	22.82	23.8	29.68	30.36	34.93	meters
DRE.05		133.17	123.51	133.17	133.17	123.51	133.17	123.51	123.51	123.51	123.51	133.17	123.51	133.17	degrees
DRE.06		19.46	20.27	19.46	19.46	20.27	19.46	20.27	20.27	20.27	20.27	19.46	20.27	19.46	cm
DRE.07		19.46	20.27	19.46	19.46	20.27	19.46	20.27	20.27	20.27	20.27	19.46	20.27	19.46	cm
DRE.08		840	840	840	840	840	840	840	840	840	840	840	840	840	MHz
DRE.09		35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	35.71	cm
DRE.10		280	280	280	280	280	280	280	280	280	280	280	280	280	MHz
DRE.11		4.09	2.11	1.73	1.45	1.45	1.45	1.29	1.29	1.22	1.17	1.17	0.92	1	MHz
DRE.12		200	388	472	564	564	564	636	635	671	699	697	892	821	
DRE.13		11.24	7.74	5.39	4.64	5.65	4.64	5.11	5.12	4.89	4.71	3.87	3.83	3.36	days
DRE.14		700	1304	1652	1972	2844	2958	4272	5330	6193	7044	6710	7490	7180	
DRE.15		4.2	7.82	9.91	11.83	17.06	17.75	25.63	31.98	37.16	42.26	40.26	44.94	43.08	M\$
DRE.16		0.31	0.61	0.74	0.88	1.33	1.32	1.99	2.48	2.89	3.28	3	3.49	3.21	M\$
DRE.17		0.2	0.95	2.66	4.52	4.36	6.78	8.31	10.33	13.39	16.56	23.55	28.67	34.91	M\$

Scientific Parameters

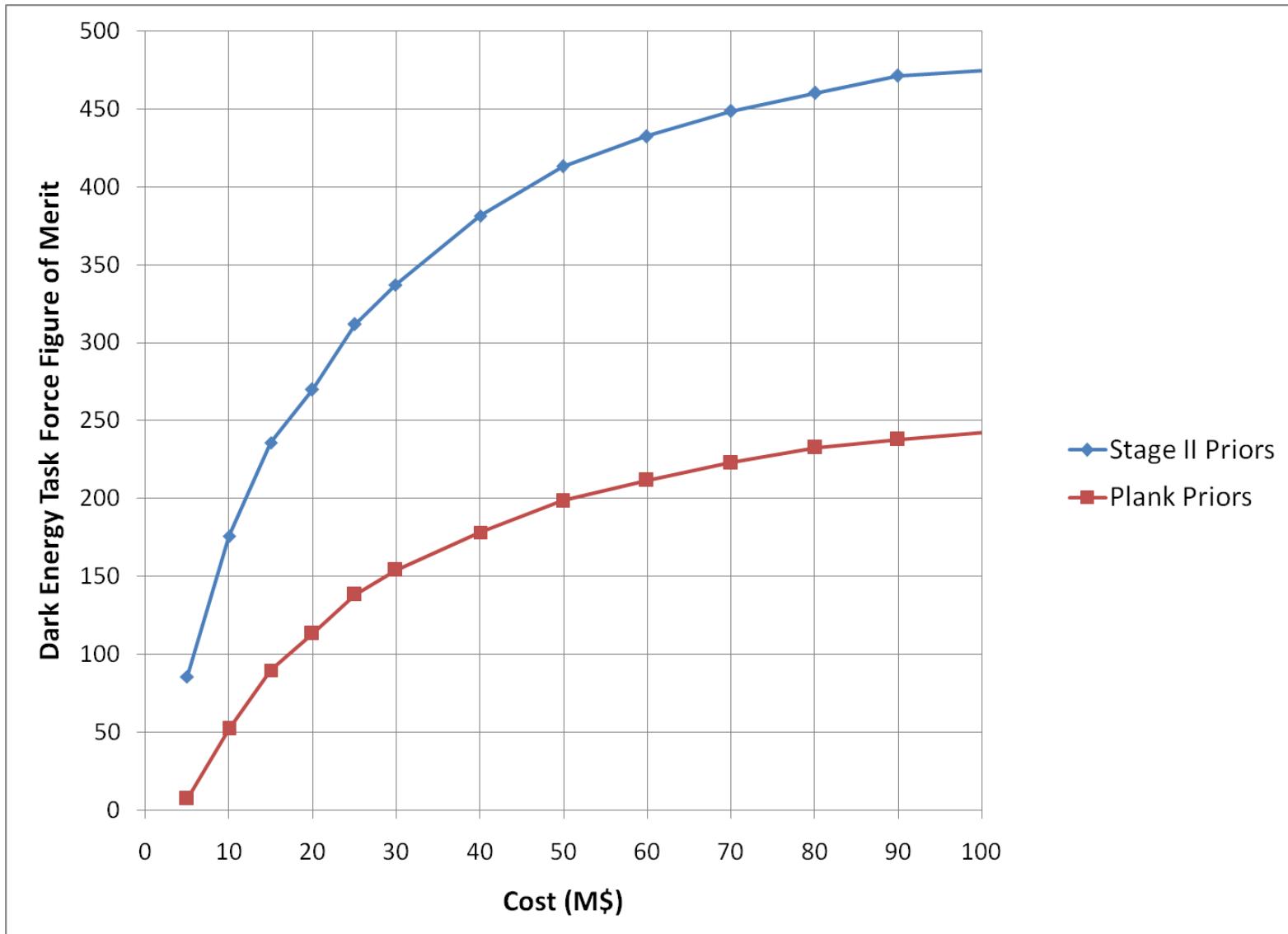
Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
SCI.01 - SCI.02 Redshift Range	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
SCI.03 Survey Area	2.81	2.9	2.81	2.81	2.9	2.81	2.9	2.9	2.9	2.9	2.81	2.9	2.81	2.81
SCI.04 Angular Resolution	33.65	18.58	14.26	11.94	12.78	11.94	11.34	11.36	10.76	10.32	9.65	8.09	8.2	arc-min
SCI.05 Sensitivity per Pixel	47.92	88.24	104.74	123.8	82.28	82.14	70.01	57.26	55.52	53.53	58.33	78.33	73.4	uK
SCI.06 Plank Priors Figure of Merit	7.42	52.28	89.67	113.32	138.2	153.96	178.23	198.43	211.6	222.86	232.45	237.88	242.19	
SCI.07 DE II Priors Figure of Merit	85.58	175.9	235.84	269.75	311.76	337.08	381.2	412.95	432.37	448.41	460.06	471.24	474.71	

Band 1

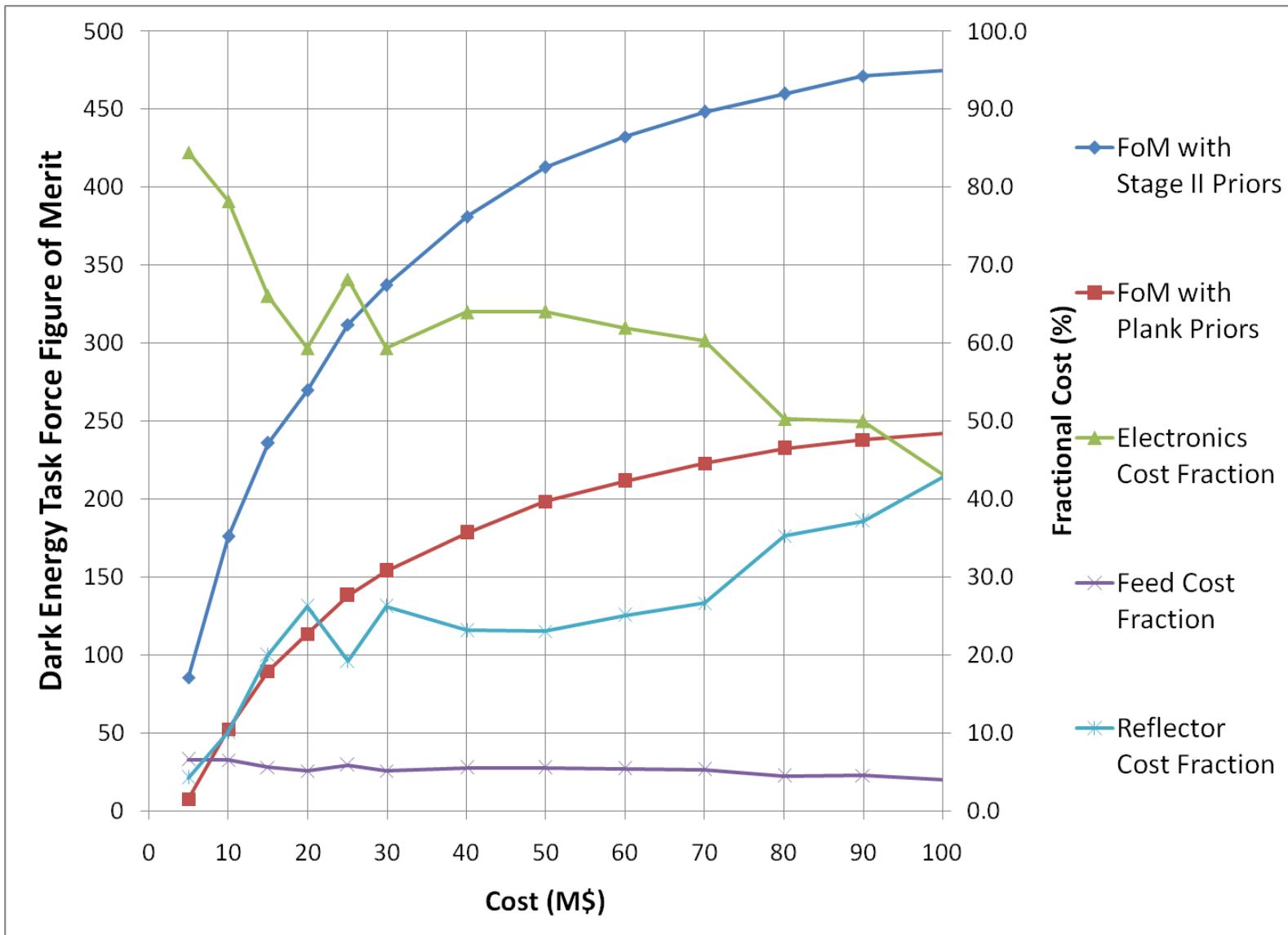
Cost	5	10	15	20	25	30	40	50	60	70	80	90	100	M\$
SCI.01 - SCI.02 Redshift Range	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
SCI.03 Survey Area	3.05	2.9	3.05	3.05	2.9	3.05	2.9	2.9	2.9	2.9	3.05	2.9	3.05	3.05
SCI.04 Angular Resolution	36.05	18.58	15.28	12.8	12.78	12.8	11.34	11.36	10.76	10.32	10.34	8.09	8.79	arc-min
SCI.05 Sensitivity per Pixel	41.32	84.48	91.53	107.73	79.74	72.95	68.66	56.88	55.43	53.9	54.05	77.94	67.54	uK
SCI.06 Plank Priors Figure of Merit	7.42	52.28	89.67	113.32	138.2	153.96	178.23	198.43	211.6	222.86	232.45	237.88	242.19	
SCI.07 DE II Priors Figure of Merit	85.58	175.9	235.84	269.75	311.76	337.08	381.2	412.95	432.37	448.41	460.06	471.24	474.71	

Band 2

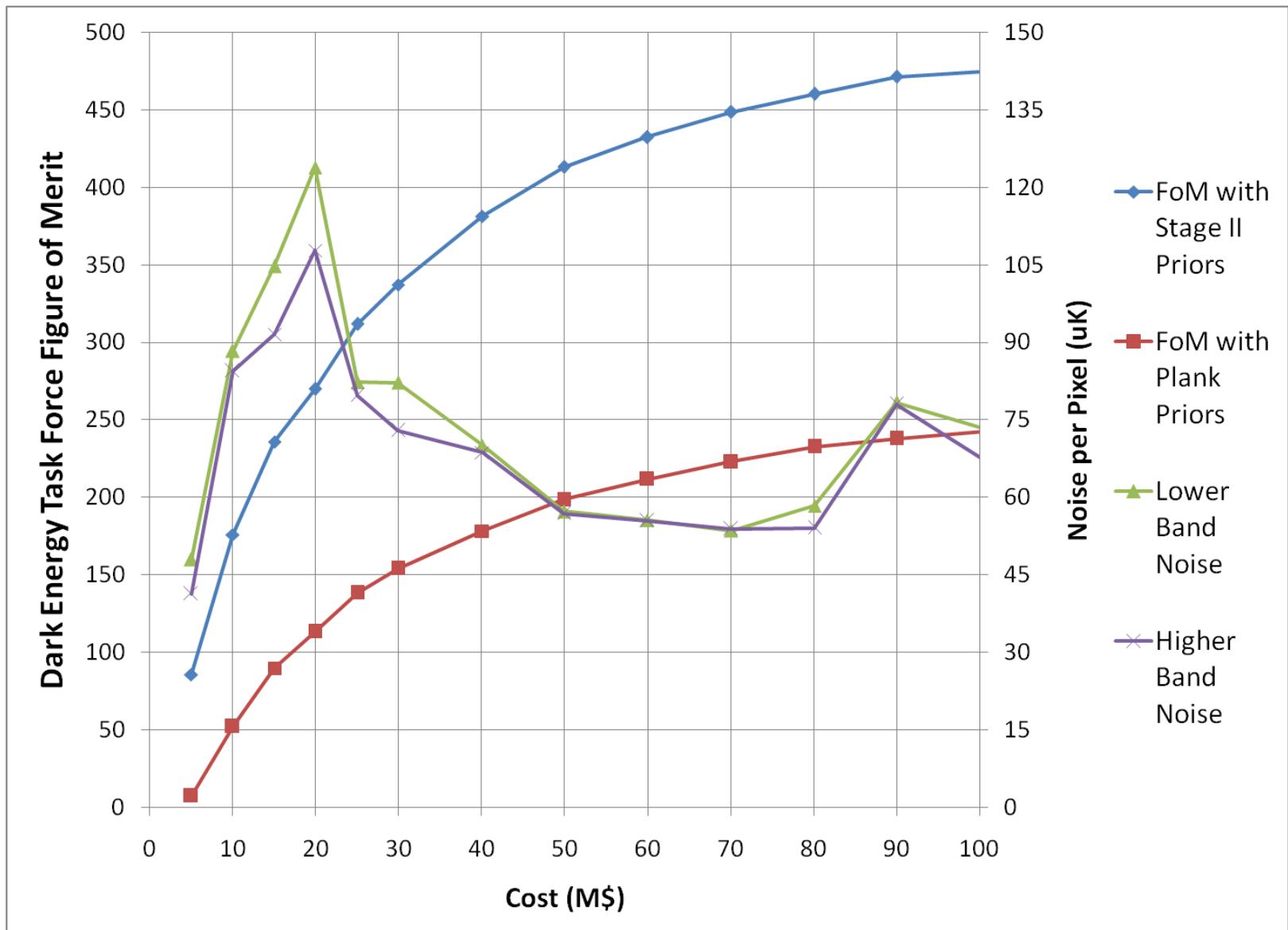
Figure of Merit vs Cost



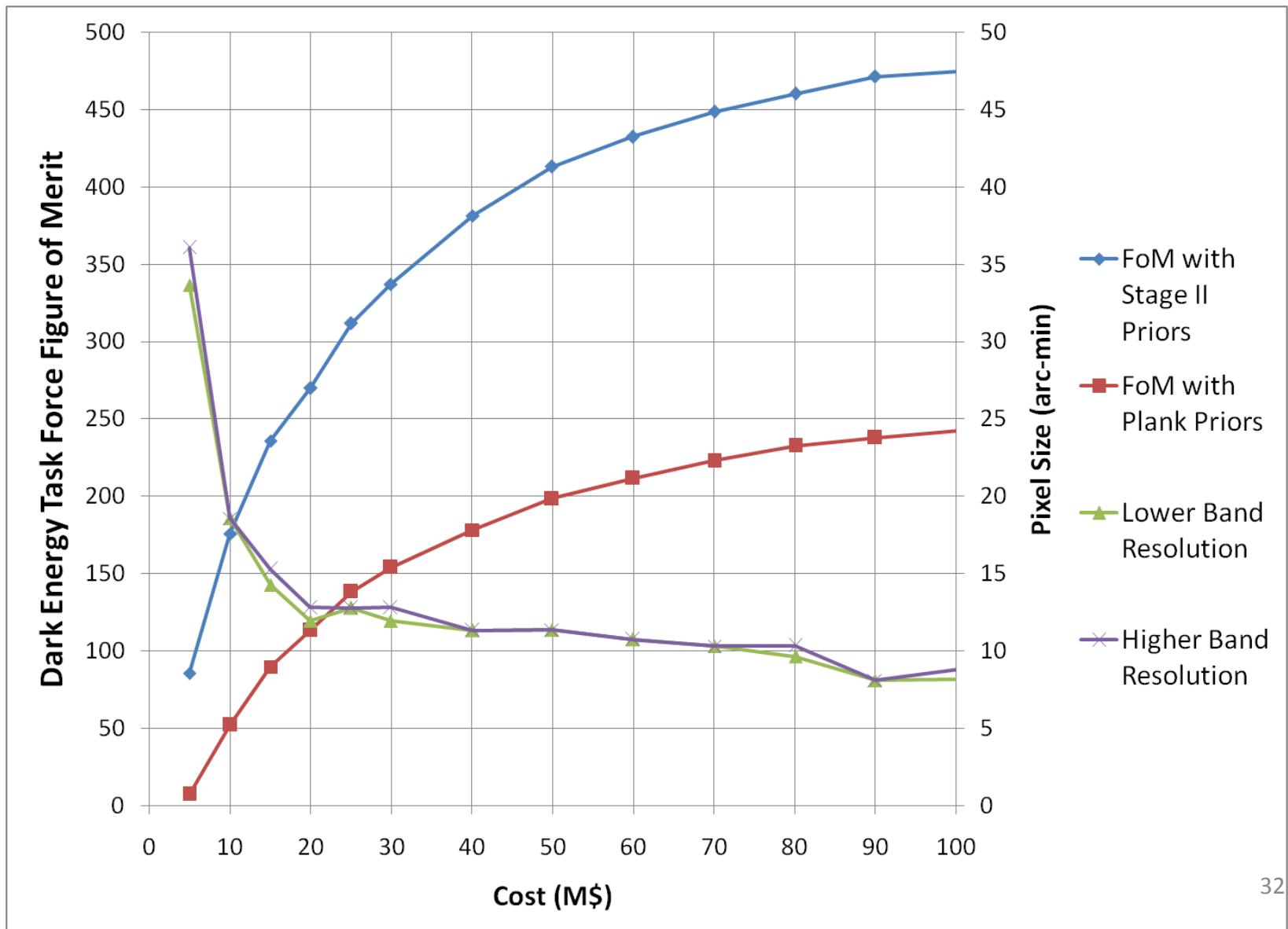
Fractional Cost



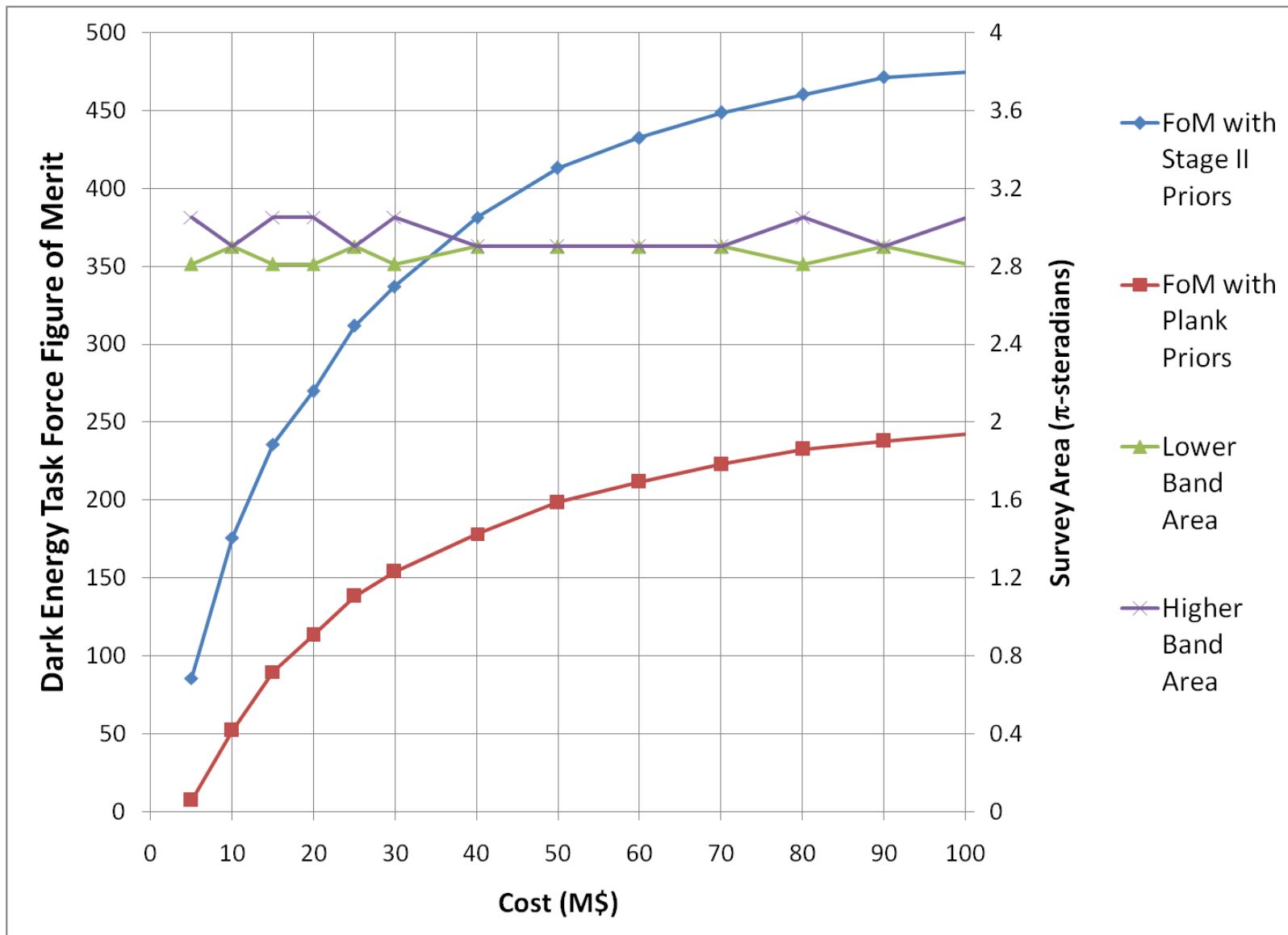
Noise Per Pixel



Pixel Size



Survey Area



Conclusions

- A Dark Energy Task Force Figure of Merit of 250 can be obtained with a CRT that “costs” $\sim 15\text{MS}$
- Sensitivity is the most important factor in increasing the FOM for a fixed cost

